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Remote Sensing and Aerial Survey of Vegetation Cover Change in Lowland Peat Swamp of Central Kalimantan during the 1997 and 2002 Fires

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Abstract

Peat swamp forests play important roles in the regulation of hydrology, the maintenance of biodiversity and in global climate regulation. In tropical areas they are being depleted by logging and land conversion activities, especially by fires. In autumn 1997, fire raged out of control in the “Mega-Rice Project” area in Central Kalimantan, Indonesia, where over one million hectares of land was earmarked for conversion into agricultural land. The impact of this fire on the vegetation in this area was studied using satellite remote sensing imagery and by ground and aerial surveys. This study focuses on the use of interferometric synthetic aperture radar technique in mapping vegetation cover change. ERS SAR imagery over the area of interest was acquired during two tandem missions in April 1996 and October 1997. The change in vegetation cover was mapped by comparing the change in coherence and backscatter intensity. The results of the ERS SAR analysis were checked on the ground and during aerial surveys in part of the study area in June and November 1998 and August 1999. Comparison with SPOT images acquired during the fire period and Landsat TM images acquired before and after the fire period confirms the interpretation of the ERS interforemetric SAR images. NOAA images to count hot spot information were also used.

New huge fires were observed in autumn 2002 (End July to End of October) over the island of Borneo caused by draughts of the next El Nino Southern Oscillation (ENSO) five years later. Fires and smoke can be detected with the NOAA and with the MODIS sensor (e.g. on 18. Aug. 2002) covering the whole period. It seems that now every year for several months during the dry period smoke and haze conditions around Palangkaraya and the MRP area become the norm.

1. Introduction

Indonesia has the largest area of peatlands in the tropics. Indonesian Kalimantan possesses 6.4 to 9.2 million ha of lowland peatlands, which is approximately half of Indonesia's peatlands (Rieley et al. 1996). The southern part of the Central Kalimantan province around the capital Palangkaraya has one of the major peat swamp forest habitats (about 2.2 Mha) in Indonesia. Peat swamp forests are important ecosystems. They play important roles in the regulation of hydrology (flood prevention, sources of fresh water, prevention of saline water intrusion) and the maintenance of biodiversity and are sources of timber and non-timber natural products (Silvius and Giesen 1996). Peatlands also play an important role in global climate regulation. It has been estimated that the carbon stocks held by peatlands account for 35% of total terrestrial carbon (Maltby and Immirzi 1992). Release of the carbon stocks into the atmosphere due to peat fires and non-sustainable development would contribute to global warming (Pages et al. 2000 and 2002). Peat swamp forests act as carbon sinks and regulate climate via evapotranspiration and heat absorption.

Peatlands have traditionally been viewed as “wastelands” to be reclaimed for development. In recent years, tropical peat swamp forests are being threatened by anthropogenic activities, which include logging and conversion to agricultural land use (Riswan and Hartanti 1995, Rieley and Ahmad-Shah 1996, Phillips 1998). The reclamation process normally involves draining the swamps with ditches, which are usually laid out in a grid pattern (Notohadiprawiro 1996, 1998 and 1999). The lands are then usually cleared by the cheapest means, i.e. by the use of fires (Goldammer 1997). In 1997, during the dry season from July to November, fires raged out of control in the tropical forests of Sumatra and Kalimantan, aggravated by the severe drought brought by the El-Nino Southern Oscillation effect. The peat swamp of Central Kalimantan was among the three main peat swamp areas in Indonesia affected by the 1997 fires (Barber and Schweithelm 2000 and Boehm and Siegert 2000), the other two were in West Kalimantan and South Sumatra (Liew et al. 1998). Peatlands are prone to burning during droughts due to their high carbon reserve (Pages et al. 2000 and 2002). It has been reported that peat fires may spread underground, destroying the root systems of the standing trees, and resulting in complete destruction of the forests. Peat fires are usually smouldering fires with high particulate emissions. During the 1997 fire episode, the smoke haze spreading to the neighbouring countries has been estimated to have resulted in a loss of billions of US dollars (SEAEEP and WWF 1999). In addition to the transboundary pollution, the effects of forest fires on the environment include the loss of biodiversity, loss of forests as carbon sinks and emission of greenhouse gases with potential contribution to global warming (Levine 1991, Zepp 1994, Levine 1996, Pages et al. 2000 and 2002).

In this study, the specific area of interest is an area in Central Kalimantan where more than one million ha of peatlands, comprising virgin and logged-over forests as well as existing agricultural sites, have been earmarked for conversion into a vast area of irrigated rice fields and plantations. This “Peat Land Project” (Proyek Lahan Gambut) was initiated in June 1995 by Presidential Decree No. 82/95 (Development of One Million Hectares of Peatland for Food Crop Production in the Province of Central Kalimantan, Peat Reclamation). It is popularly known as the “Mega-Rice Project” (MRP). Construction of irrigation/drainage channels began in April 1996. More than 4,500 km of channels have so far been constructed, draining and desiccating the peatlands. The environmental implications of the project have alerted the scientific community. In an International Symposium “Biodiversity and Sustainability of Tropical Peatlands” held in Palangkaraya, Central Kalimantan, Indonesia, 4 - 8 September 1995, the delegates prepared a statement emphasising the importance of tropical peat ecosystems, urging governments, planners and developers to prepare policies for sustainable use of tropical peatlands (Rieley and Page 1996). After three years in operation, the MRP had failed to achieve its goal (Notohadiprawiro 1996, 1998 and 1999). The dried-up peatlands were ravaged by fires from July to November, 1997, contributing to the smoke-haze pollution in the entire Southeast Asian region during this period. The mega rice project was officially terminated in July 1999. However, a new project KaKaB (Kahayan, Kapuas, Barito) has been established by presidential decree No. 80/1999, issued in July 1999 (General planning guidelines and management of peatland development area in Central Kalimantan) in which a significantly larger area (2.8 Mha) will be developed and converted into mostly palm oil plantations.

It is important to monitor the extent of change in forest cover in the peat swamp area in order to assess the impacts of the anthropogenic activities to the environment. Satellite remote sensing is an effective and cost-efficient method of monitoring/surveying of landcover changes (Malingreau 1990). Several satellite sensor platforms are currently available. The AVHRR sensor on board the NOAA satellites can provide a 1-km resolution vegetation index map using the two visible and near infrared bands. The third band (3.8 µm) is used for detecting hot spots due to fires (Matson et al. 1987, Kaufman et al. 1990, Robinson 1991, Arino and Melinotte 1998, Siegert and Hoffman 1998, Nakayama et al. 1999). The optical and infrared bands of the Landsat-TM and SPOT-HRV sensors provide high resolution images (30 m for Landsat 5, (TM7

ETM PAN channel for 15m) and 20 m for SPOT (PAN channel 10m)) for land cover mapping, burnt scars delineation and monitoring of land cover change.

One major limitation of optical/infrared remote sensing imagery lies in the inability of optical/infrared radiation to penetrate clouds and thick haze. The cloud-penetrating ability of radar provides an alternative method of monitoring land cover changes. Synthetic aperture radar (SAR) imagers are carried on-board the ERS-1 and ERS-2 satellites. The orbits of the ERS satellites are identical except that ERS-2 lags ERS-1 by one day. This configuration of the two satellite orbits provides a unique opportunity for performing interferometric SAR in the tandem mode, i.e. a location on earth can be imaged by the two satellites with identical geometry with a one-day interval.

SAR backscatter intensity and interferometric coherence have been used in forest mapping and monitoring (Wegmuller and Werner 1995, LeToan et al. 1996, Askne et al. 1997, Stussi et al. 1997, Liew et al. 1999, Siegert and Hoffmann 1998, Siegert et al. 2001). In particular, tropical forests are known to have a constant backscattering coefficient between -7 and -6 dB in C-band. The interferometric coherence of the vegetated area is typically low compared with clear cut or sparsely vegetated area. If multi-temporal SAR data of an area of interest are acquired, clearings of forests/vegetation can be detected by an observed change in backscatter intensity and/or an increase in coherence of the area.

In this paper, we describe the use of satellite remote sensing and aerial survey in mapping vegetation cover changes in the MRP area of Central Kalimantan, Indonesia, during the 1997 and 2002 forest fire episode. We focus on the use of the interferometric synthetic aperture radar (SAR) technique in mapping vegetation cover change. SAR imagery over the area of interest was acquired during two tandem missions of the ERS satellites in April 1996 and October 1997. The forest cover is characterised by a high radar backscatter intensity and low interferometric coherence. By comparing coherence and backscatter intensity data acquired during the two periods, the change in vegetation cover can be mapped and the extent of areas affected by the 1997 fires can be estimated. The results of the ERS SAR analysis were checked on the ground and during aerial surveys in part of the study area in June and November 1998 and August 1999. Comparison with SPOT images acquired during the fire period and Landsat TM images acquired before and after the fire period confirms the interpretation of the ERS interforemetric SAR images.

The hot spots detected by the NOAA Satellite are shown for the 1997 and 2002 fires as well as Modis sensor information taken on 18. Aug. 2002 from strong smoke plumes.

2. Study Area

The location map of the study area that covers four ERS frames is shown in Fig. 1A and 1B. Each ERS frame has a nominal dimension of 100 km by 100 km. The study area is located in the southern part of Central Kalimantan, drained by the Sebangau, Kahayan, Kapuas and Barito rivers. A Landsat TM image of this area acquired on 29 May 1997 is shown in Fig. 2. This image was acquired after the construction of irrigation/drainage channels had begun, but before the large scale 1997 fire event. Thus, it gives a snapshot of the MRP area before the full scale implementation of the project. In this image (RGB = Bands 543), peat swamp forests (PSF) are indicated in dark green while the lighter green areas are forests that have been opened up. The relatively dense PSF exist mainly in the western and northern portions of the image. The peat swamp forest west of Sebangau river remains relatively untouched. Aerial photos of two types of PSF in this region are shown in Fig. 2, below the TM image. The pinkish areas in the TM image are cleared lands for agriculture or settlements. Networks of irrigation channels can clearly be seen in these regions, especially at the lower right quadrant of the image. Most of these channels were the old channels constructed by the early settlers for rice cultivation. Channels connecting big rivers such as the Barito, Kapuas and Kahayan rivers were built by the Netherlands Indians government in late 19th and early 20th century, during the colonial era. These channels also provide waterways, making the area between the cities of Banjarmasin, Kuala Kapuas and Palangkaraya accessible. GPS (Global Position Sensor) tracks from a Nov. 1998 aerial survey (red trails) and ground survey (blue trails) are superimposed on the GIS image (Geographical Information System).

3. Mapping Vegetation Cover Change Using Interferometric SAR Images

The ERS dataset used in the study is shown in Table 1. It was acquired during two tandem missions in March/April 1996 and October 1997, and processed to the level of Single-Look Complex (SLC). Altogether 8 pairs of tandem-SLC data were used. Each pair of the SLC images was first co-registered and the coherence and intensity images were generated. All SAR images were acquired and processed at the Ground Station of the Centre for Remote Imaging, Sensing and Processing (CRISP), Singapore. Details of the interferometric SAR processing have been described elsewhere (Stussi et al. 1996, Stussi et al. 1997, Liew et. al. 1999). Post-processing of the images consists of antenna pattern correction, slant range to ground range correction for transforming the images to map coordinates and speckle removal using an adaptive noise smoothing filter.

Pseudo-colour mosaics of the SAR coherence-intensity images were generated. Extracts of the mosaics covering most parts of the MRP area are shown in Fig. 3 and Fig. 4 for the 1996 and 1997 datasets respectively. In each mosaic, the interferometric coherence is shown in the red display channel, the ERS-2 backscattered amplitude in the green and blue display channels. Vegetated areas appear in shades of cyan and non-vegetated areas in shades of red. The brighter cyan areas are more densely vegetated than the darker cyan areas. The dark red areas have low radar backscatter but high coherence. Rivers, catchments and inland water masses appear in black due to low coherence and low backscatter. Settlements and built-up areas appear as bright white. The Central Kalimantan province capital, Palangkaraya (labelled P in Fig. 3), can be seen in the two images.

Most areas in the April 1996 image (Fig. 3) are cyanic in colour, showing the presence of PSF. In the Oct. 1997 image (Fig. 4), the deforested regions can be detected visually. The Parent Primary Channel (PPC in Fig. 4) constructed for the MRP connecting the Barito river in the east and the Kahayan river near Palangkaraya in the west can be seen. Extensive networks of channels are visible between the Barito and Kapuas rivers. Much of the land has been cleared (e.g. the Dadahup area, labelled A in Fig. 4), presumably by fires. Some areas in between the channels appear dark (B and C in Fig. 4), indicating a low interferometric coherence and low radar backscattered intensity. Aerial surveys (described in later sections) reveal that these areas are occupied by standing dead trees. The dead trees have low biomass, resulting in low radar backscatter. However, the remaining dead tree branches probably result in loss of coherence in the interferometric data.

Two vegetation cover maps (Fig. 5 for Apr. 1996 and Fig. 6 for Oct 1997) of the study area were generated from the two tandem ERS SAR datasets by thresholding the coherence and intensity. For each dataset, a threshold of 0.5 was applied to the coherence data to separate the land into two major classes: low coherence (<0.5) areas consisting of vegetation and open waters and high coherence (>0.5) areas consisting of clear cuts or settlements. The low coherence areas were further separated into four more classes by thresholding the intensity. The low-coherence class with the lowest intensity was the water body. The resulting five classes in the vegetation cover maps are: 1. non-vegetation with high coherence (clearings or settlements, coloured red in Figs. 5 and 6); 2. vegetation with high radar brightness (forest with high biomass, green in Figs. 5 and 6); 3. vegetation with medium radar brightness (burnt forest or degraded forest with low biomass, dark green in Figs. 5 and 6); 4. vegetation with low radar brightness (grass or sparse vegetation areas, yellow in Figs. 5 and 6); 5. Water body (blue in Figs. 5 and 6).

Changes in land cover between April 1996 and Oct. 1997 can be derived by comparing the two corresponding vegetation cover maps. The resulting land cover change map is shown in Fig. 7 and Table 2 shows the results of this change analysis. In Fig. 7, the areas affected by the 1997 fire are coloured in red and orange. They occupy about 25% of the total land area in the ERS images. The red areas have low coherence in 1996 and an increase in coherence in 1997. These areas are new clearings and are possibly burnt areas. The orange areas are standing dead trees due to fires. The coherence remains low both in 1996 and 1997. However, the radar backscatter decreases in 1997 due to a decrease in biomass. The areas coloured green and dark green are vegetated in both 1996 and 1997. The white areas are the old clearings and settlements. They have high coherence in both the 1996 and 1997 imagery. Old clearings with vegetation regrowth (i.e. high coherence in 1996 but decreased coherence in 1997) are coloured yellow in Fig. 7. Approximately 25% (913 000 ha) of the vegetation (mostly PSF) in the study area has been burnt.

4. Comparison with Optical Remote Sensing Images

Multi-spectral SPOT images of parts of the study area were acquired on July and September 1997. SPOT quick-look images are shown in Fig. 8. The June and September 1997 images illustrate the situation during the active fire period in 1997. In the mosaic of SPOT images, several intense smoke plumes can be seen emanating from the sites of active fires, especially in the September 1997 scene. The reddish regions are vegetated while the dark areas have been burnt. The parent primary channel (labelled PPC) can be detected. The dark green areas near to the channels in Fig. 4 (labelled B and C) are indeed burnt vegetation. This SPOT mosaic confirms that most of the areas delineated as burnt vegetation in the land cover change map derived from interferometric SAR images (red and orange areas in Fig. 7) have been affected by the fires of 1997.

Two cloud-free Landsat-TM images of the study area were acquired on 10 May 1996 and 29 May 1997, before the 1997 fires. Another image (hazy) acquired on 29 March 1998 (after fire) was also available. Extracts from these images for an area vastly affected by the 1997 fires near Dadahup are shown in Fig. 9 (A and C). The spectral characteristics of fire scars in Landsat TM images of Amazonian forests have been studied by Pereira and Setzer (1993). They found a combination of channels 4 and 5 is the best for separating burn scars from tropical forests and pastures. The TM images in Fig. 9 are displayed with bands 5, 4 and 3 in the red, green and blue display channels respectively.

For comparison, extracts of the ERS interferometric SAR pseudo colour composite images of Apr. 1996 (from Fig. 3) and Oct. 1997 (from Fig. 4) covering the same area are shown in Fig. 9 (B and D). In the TM images, PSF is shown in green colour, clear-cut in red and magenta colours. The bright yellowish areas are open land with sparse vegetation and regrowth. Newly built channels are seen in the 1998 TM images as well as in the Oct. 1997 ERS interferometric SAR image. As can be seen in the time series, most of the remaining PSF in the area have been destroyed by the fires. The high coherence areas (reddish) in the ERS interferometric SAR images correspond to the reddish and yellowish areas in the TM images. The burn scars in the 1998 TM image appear reddish in colour due to a high reflectance in band 5 (short-wave infrared band) and low reflectance in bands 4 (near infrared) and 3 (visible red). Parts of areas delineated as burn scars in the ERS SAR images appear yellowish in the 1998 TM image (e.g. on the west bank of the Barito river, near the top half of the image), indicating the emergence of some sparse vegetation such as grass and shrubs in the burn areas which are identified as regrowth of vegetation. The reddish areas in the left half of the 1998 after-fire TM image appear to be larger than the corresponding area delineated as burn scars in the ERS image. This is probably due to the continued occurrence of fires in this area after the October 1997 acquisition of the ERS image. During the fires between End of July and End of October 2002, NOAA and Modis images were acquired from the internet. A Landsat image from 20th August 2001 (Fig. 17) shows fires and smoke plumes of the MRP study area even one year before the next 2002 huge fires.

5. Aerial and Ground Surveys in 1998, 1999, 2000 and 2001

To investigate fire impact and to survey several locations suspected as being burnt in the ERS and Landsat TM images, three aerial and three ground surveys were conducted in June and November 1998, and in August 1999 (Boehm and Siegert 1999, Boehm et al. 1999). Ground trials in June 2000 and July/August 2001 were added. During the November 1998 flight, total flight time of 2 hr 30 min and flight distance of 400 km were logged by GPS. The flight route was planned by storing ERS SAR map co-ordinates of interest (derived from a geo-referenced ERS image) within part of the fire affected area into the GPS of the aeroplane. The flight route was then recorded by GPS in continuous track mode storing geographic locations every 10 seconds. The flight survey was also documented by digital video. In order to facilitate later analysis of the video material and comparison with satellite images, video time code and GPS system time were synchronized. Similarly all travels on the ground were recorded by GPS in a 30 seconds interval and approx. 500 photographs were taken at know geographic locations. To check classification results, the GPS tracks were imported into a GIS (Geographical Information System) containing the geo-referenced ERS and Landsat TM satellite images (compare Fig.2). By overlaying the GPS tracks onto the satellite images and by comparing photographic and digital video information, specific signatures and features in the ERS images were checked.

Aerial surveys were mandatory since many areas in the test area could not be accessed on the ground. First of all, the infrastructure in Central Kalimantan is very poorly developed, many of the new channels cannot be travelled by boat due to a low water table in the channels. Fire affected forests and selective logged forest are almost hardly inaccessible on foot. These surveys revealed that, in general, fire in PSF almost completely destroyed the vegetation. Tree survival rate was estimated during the aerial survey to be less than 10%. Due to the extended drought period caused by the 1997/98 El Nino episode and aggravated by the newly made channel system which completely drained the peat domes, the water level in the peat swamps dropped several meters. This resulted in an extremely dry upper layer of peat which when set on fire produced huge amounts of smoke, haze and CO^2 emission. Since the fire affected the soil itself (the peat layer) it destroyed the root system of the trees which in consequence toppled over. In most cases low pole PSF have been consumed completely by the fire, while in high PSF, trees have been killed but not combusted. The completely destroyed forests show up as areas of high coherence in the Oct. 1997 interferometric SAR image (reddish areas in Fig. 4). On the other hand, the burnt forests with standing dead trees have low interferometric coherence. These burnt forests can be discriminated from live vegetation by their generally low SAR backscatter in the interferometric SAR image (dark areas between channels in Fig. 4).

Figures 8A, 8C, 8E are SPOT quick look images of the study area acquired on 6. June, 29. July and 8. September 1997, before and during the fires. Several smoke plumes due to fire activities can be seen clearly in Fig. 8C and 8E. Figure 8B and 8F show ground photos in the Dadahup area and Figure 8D an aerial photo with new transmigration houses.

Figures 9A and 9C show LANDSAT-TM images (RGB = Bands 543) of the Mega Rice Project area in Central Kalimantan near Dadahup acquired on 10 May 1996 before the 1997 fire (top left panel 9A) and on 29 March 1998 after the fire (bottom panel 9C). Each image covers an area 44km by 58km. Peat swamp forests appear in shades of green, clear-cuts in shades of pink and purple. Burnt areas appear in red in panel 9C. The letters and arrows in panel 9C indicate the locations of the aerial and ground photos shown in Figures 10 and 11. For comparison, ERS interferometric SAR images of April 1996 (before fire, top right panel 9B) and Oct. 1997 (during fire, bottom right panel 9D) extracted from Fig. 3 and Fig. 4 are also shown. Fire impact was concentrated along the main and side channels. There were no examples of fire scars within closed forests (e.g. caused by self-ignition). This pattern confirms conjecture that most if not all fires can be attributed to arson. Fire was used for cheap land clearing in the framework of the Mega Rice Project.

Figure 10A shows an aerial view of the main channel connecting the Kahayan, Kapuas and Barito rivers (see Fig. 2 and Fig. 4). The Photos in Fig. 10B and Fig. 11C were acquired in the middle between Kahayan and Kapuas river at blackwater river Mentangai, where the peat dome is several meters thick. On both sides of the channel the PSF has been destroyed to 100%, but many trees are still standing and represent an extremely high future fuel hazard during the next prolonged dry season.

Figure 11A shows a black and white ERS-image (18 Sept. 1997) with the rivers Kapuas and black water river Mentangai, the new channels and superimposed the flight route from 3 Nov. 1998 (dotted red lines), while Figures 11B presents a LANDSAT-TM image (10 May 1996, RGB = 543) of the same area without small channels. Fig.11C is an aerial photo of the Mentangai river crossing the main channel. Channel construction had to be interrupted because of the river. Figure 11D monitors illegal logging along the Mentangai river. Figure 11E shows dead trees along Mentangai river, remnants from the great fire in 1997. In this case the fire was not strong enough to combust the trunks of the trees probably because it was a smouldering fire propagated in the peat layer. Figure 11F presents a new transmigration settlement established on the land cleared by fire in 1997 (compare LANDSAT image in Fig. 2 and 11B) but not yet inhabited, location indicated by arrow in Fig. 11A.

6. Fires in 2002

The 2002 fires started at the End of July 2002 in Borneo island. Pak Suwido Limin from University of Palangkaraya and director of CIMTROP writes on the 29. July 2002:
"CENTRAL KALIMANTAN IS ON FIRE AGAIN! A PLEA FOR URGENT ASSISTANCE! A fire fighting team, 'Tim Serbu Api' (TSA) under my direction is working hard to suppress fires in Block C of the former Mega Rice Project area, near to the Kalampangan Channel in Central Kalimantan Province of Indonesia. We started on Friday 25th July 2002 and worked without rest or stopping, every day and night. So far we have successfully installed deep wells below this peat covered landscape in three locations and obtained water to wet the peat surface along a transect line 800-900 metres long to try to stop the fire from spreading to the nearby village and destroying crops, houses, forest and peat……The National, Provincial and Local Governments are powerless to do anything, only meeting and talking, while destruction takes place around them. All of the people in and around the Provincial capital of Palangka Raya are now suffering from the choking haze and smoke. The conditions are terrible and many children will become ill, some permanently. We desperately need help to extinguish these fires."

The satellite information from NOAA and Modis sensors documents this 2002 situation from the sky. Figure 12 shows accumulated NOAA hot spots in August 2002 from major parts of Indonesia. Especially Borneo and Sumatra produced many hot spot counts in this month. The NOAA hot spots for Borneo from 15. July to 13. October 2002 are shown in Figure 13. Around the 17. August 2002 the most hot spots with 1300 counts were visible and one month later around the 17. Sept. 2002 again high hot spot values with 760 counts were seen on the NOAA images. The fires, smoke and haze continued up to the end of October 2002.

Figure 14 presents the Island Borneo with a clear NOAA12 image from the 18. August 2002 showing smoke and haze (left). On the 10. Oct. 2002 image many clouds are visible covering the north part of Borneo (right). In the southern area hot spots, smoke, plumes and haze were monitored (right). A Modis image acquired on 18. August 2002 shows many fires (Figure 15) with smoke and plumes over Central Kalimantan. Hot spot counts are compare in Fig. 13. Palangkaraya is totally covered by fires and smoke! The airport of Palangkaraya had to be closed for several weeks during this fire period. The people who had to fly to Jakarta had to use the airport of Banjarmasin.

The photos in Figure 16 are a documentation of the fire situation on the ground during September 2002 in the south of Palangkaraya. Figure 17 is a relative cloud-free Landsat image (118-62, 543) taken on 20. Aug. 2001, which represents one year before 2002 fires again strong plumes of smoke over the Block A and B of MRP in the dry season. It seems that now every year for several months during the dry period, smoke and haze conditions around Palangkaraya and the MRP area become the norm, which was predicted in 1999 (Boehm and Siegert, 1999 and Boehm et al. 1999).

7. Conclusions

This work illustrates a case of monitoring vegetation cover change using multi-temporal remote sensing imagery, complemented by ground and aerial surveys. In particular, interferometric SAR imagery acquired by the ERS satellites during two tandem missions have been used to delineate burn scars in a tropical forest region. The change in vegetation cover due to the autumn 1997 fire in the "Mega Rice Project" peat swamp forest area of Central Kalimantan has been mapped using the interferometric SAR imagery acquired during the two ERS tandem missions in April 1996 and Oct. 1997. Fire burn scars were characterized by a low interferometric coherence in the 1996 imagery and an increased coherence in the 1997 imagery, in areas where the fires had completely destroyed the forests. However, in areas where trees were killed but not completely combusted, the coherence remained low. This type of burn scar can be discriminated from the remaining living forest by a decrease in the backscattered SAR intensity. A combination of both coherence and SAR intensity is required to delineate burn scars. These observations were confirmed by ground and aerial surveys of the study area. About 25% (913 000 ha) of PSF was found to have been burnt in the study area in 1997.

Now there are more than 4000 km of channels in the MRP, which has many problems in hydrology of draining instead of irrigating the land and in big peat layers which are not suitable for rice cultivation. The big PPC between Kahayan, Kapuas and Barito (KaKaB) provides no irrigation and has a draining effect only. The eco-sociological aspects caused by large-scale transmigration are unsolved. Most transmigrants lack skills and experience with peatland.

The optical satellite images (Landsat, Spot, NOAA and Modis) and aerial photos showed that draught and/or low water-table cause trees to die. Frequent fires give forests no time to recover and the tropical climate causes quick regrowth by ferns and alang-alang, etc. Central Kalimantan PSF are highly endangered. No sustainable forest management is applied, rather illegal logging behaviour has strongly increased in 2000/2001/2002. Extreme fire risk now and in the future causes haze, smoke and illness in people. Most of the Central Kalimantan fires in 1997/1998 and 2002 were man-made. Fire was used for cheap land clearing in the framework of the MRP. Huge amounts of stored carbon were released into the atmosphere. Peatland destruction is an irreversible process which can be monitored in the time sequence (1996, 1997, 1998, 2001 and 2002) of Figs. 2, 7, 8, 9, 11 and 17. This reduces the biodiversity with loss of habitats and disturbs the hydrology, combined with losses of forest products.

It seems that now every year for several months during the dry period, smoke and haze conditions around Palangkaraya and the MRP area become the norm.

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Table 1. ERS-1/2 SLC Dataset Used in the Study, acquired by CRISP, Singapore

SLC Pair	Frame	ERS-1 Orbit (date)	ERS-2 Orbit (date)
1	3645	24998 (26 April 96)	5325 (27 April 96)
2	3663	24998 (26 April 96)	5325 (27 April 96)
3	3645	24769 (10 April 96)	5096 (11 April 96)
4	3663	24769 (10 April 96)	5096 (11 April 96)
5	3645	32513 (03 Oct 97)	12840 (04 Oct 97)
6	3663	32513 (03 Oct 97)	12840 (04 Oct 97)
7	3645	32765 (22 Oct 97)	13112 (23 Oct 97)
8	3663	32765 (22 Oct 97)	13112 (23 Oct 97)

Table 2. Percentage and total area of the classes derived from interferometric SAR datasets of April 1996 and Oct. 1997; red and orange area together is approx. 913,000 ha (25%).

Class	**Colour in Fig. 7**	**Area (ha)**	**Percent of land**
New clearings (Forests in 96, clearings and fires in 97)	Red	**379,120**	10.54
Degraded and burnt forests, standing dead trees (High radar brightness in 96, mid/low in 97)	Orange	**533,528**	14.84
Old clearings, settlements	White	211,662	5.89
Old clearings with vegetation regrowth (Bare in 96, vegetated in 97)	Yellow	206,332	5.74
Remaining forests, partly selective logged	Green	1,461,632	40.65
Remaining vegetation with low biomass (mid/low radar brightness in both 96 and 97)	Dark green	803,331	22.34
Catchments and Water bodies	Blue	(117,703)	--
Total Land Area (excluding water) of the four regarded ERS-images		**3,595,605**	**100**

Table 3. Hot Spot counts from NOAA images in Borneo during 15. July to 13 Oct. 2002

July	15.	16.	17.	18.	19.	20.	21.	22.	23.	24.	25.	26.	27.	28.	29.	30.	31.
counts	50	15	0	0	67	60	0	0	15	30	0	0	100	125	0	0	5
Aug.	01.	02.	03.	04.	05.	06.	07.	08.	09.	10.	11.	12.	13.	14.	-	-	-
counts	83	0	5	100	450	70	0	15	115	225	0	190	420	785			
Aug.	15.	16.	17.	18.	19.	20.	21.	22.	23.	24.	25.	26.	27.	28.	29.	30.	31.
counts	125	285	1300	1185	350	335	500	135	365	50	465	965	450	50	335	735	350
Sept	01.	02.	03.	04.	05.	06.	07.	08.	09.	10.	11.	12.	13.	14.	-	-	-
counts	16	160	155	145	30	145	490	100	35	90	420	280	43	48	-	-	-
Sept.	15.	16.	17.	18.	19.	20.	21.	22.	23.	24.	25.	26.	27.	28.	29.	30.	-
counts	363	750	760	320	660	425	250	16	170	255	250	40	60	350	170	10	-
Oct.	01.	02.	03.	04.	05.	06.	07.	08.	09.	10.	11.	12.	13.	-	-	-	-
counts	275	235	290	95	0	135	425	120	45	480	430	295	285	-	-	-	-

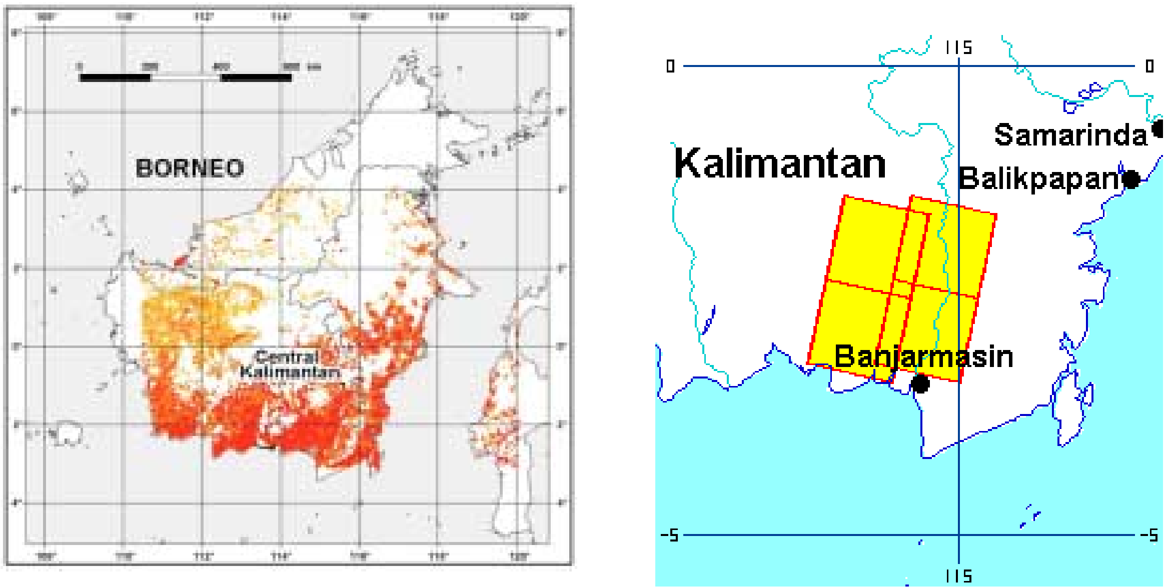
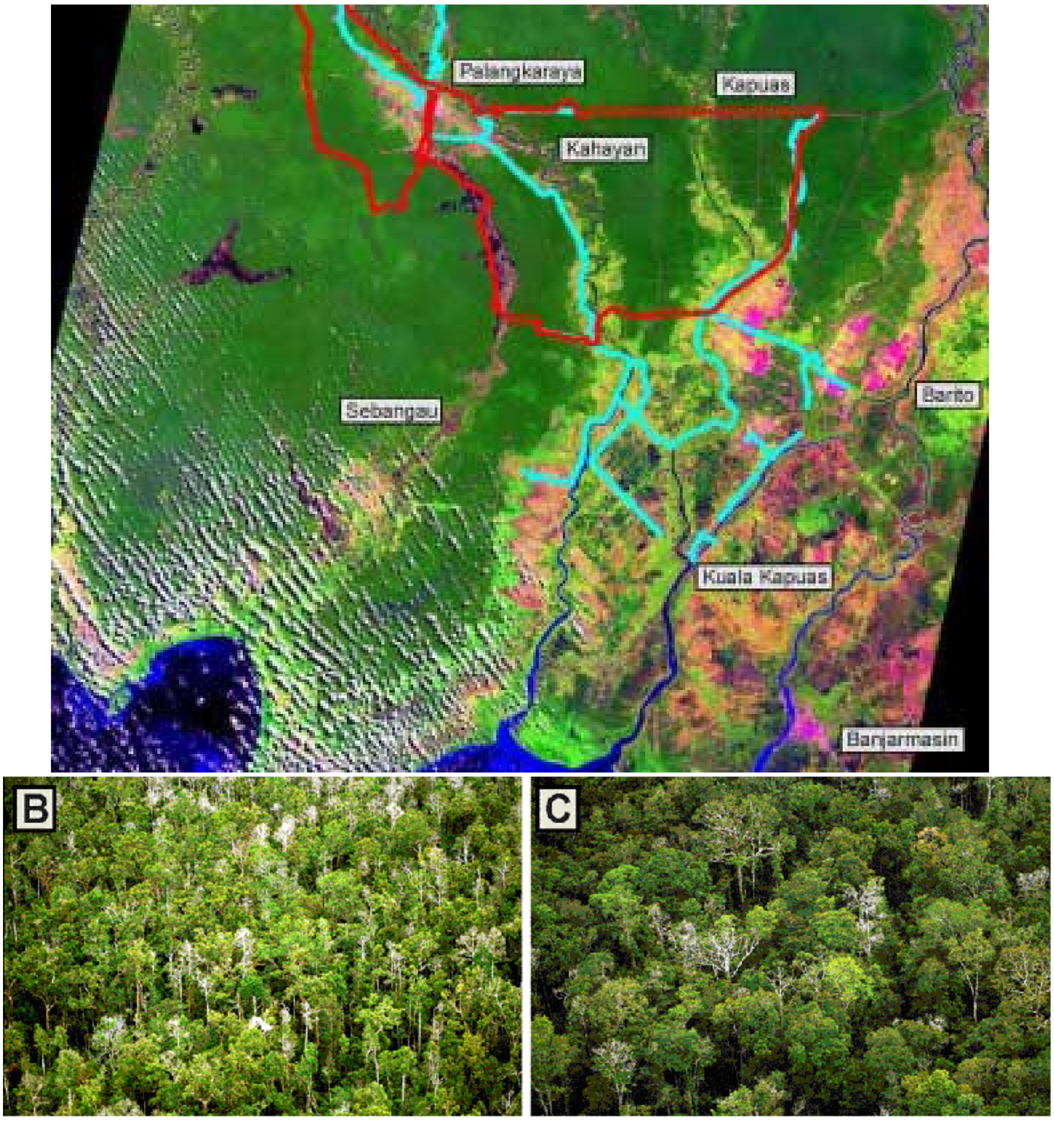


Fig. 1: A: Island Borneo with Hot Spots (yellow and red colour) collected in 1997, data courtesy by IFFM/GTZ, Samarinda **B:** Location of the study area covered by four ERS frames

Fig. 2: Landsat TM image (frame 118-62) of the study area acquired on 29 May 1997 (RGB = Bands 543) before the huge fires showing the Mega-Rice Project area in Central Kalimantan, with the channels visible especially in the Southeast quadrant of the image. GPS tracks from the Nov 1998 aerial survey (red trails) and ground survey (blue trails) are overlaid on the image. Aerial photos of two types of peat swamp forests taken near Palangkaraya at locations **B**: Low pole forest approx. 20m high near catchment of Sungai Sebangau and **C**: High peat swamp forest approx. 40m high near the centre of the peat dome are shown below the TM image.



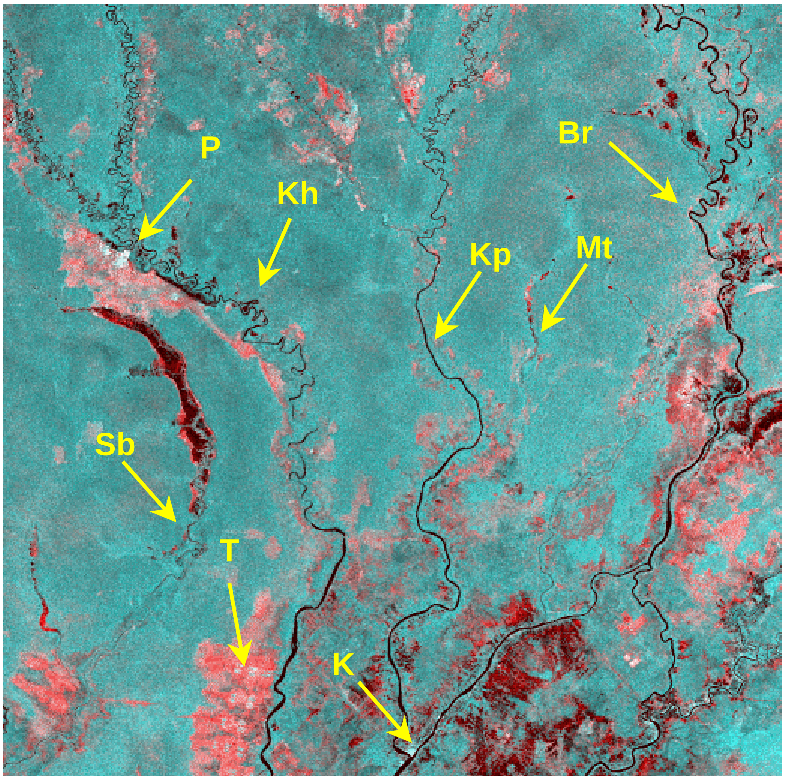


Fig. 3: Interferometric SAR false colour composite image (April 1996) showing the area between Kahayan and Barito rivers (ERS image ©ESA 1996). Br: Barito river; Kp: Kapuas river; Kh: Kahayan river; MT: Mentangai river; Sb: Sebangau river; P: Palangkaraya; K: Kuala Kapuas; T: Transmigration Settlements established in the eighties. Courtesy by CRISP, Singapore.

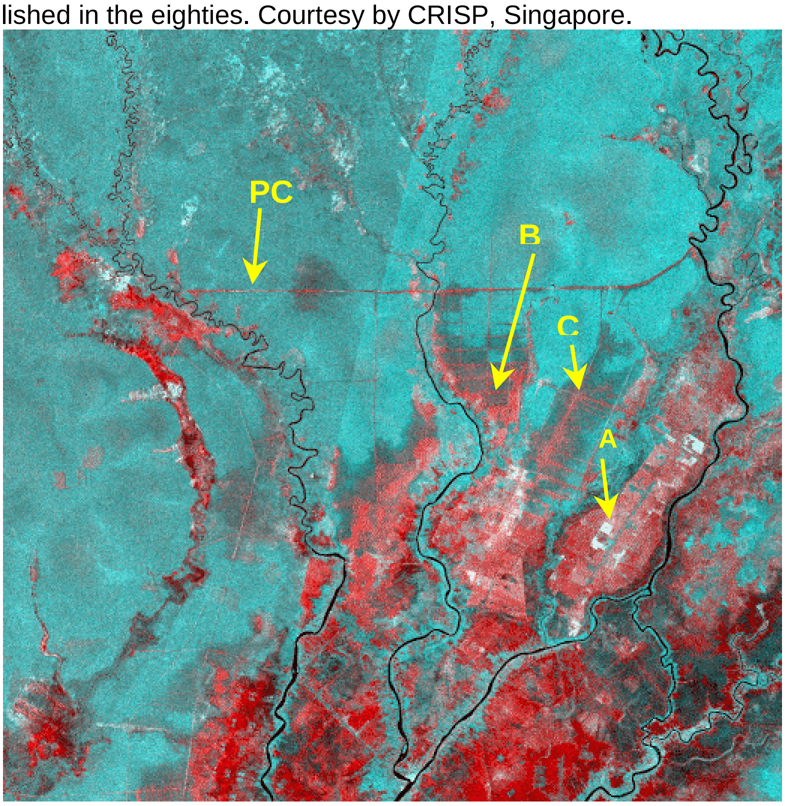


Fig. 4: Interferometric SAR false colour composite image (Oct. 1997) of the same area shown in Fig. 5 (ERS image ©ESA 1997). Light cynic areas are the remaining vegetation while red areas are land clearings. The extensive network of newly constructed channels are visible. **PC:** Parent Primary channel connecting the Barito and Kahayan rivers. **A:** Land cleared by fires in Dadahup area. **B:** Channels between Kapuas and Mentangau rivers. The dark areas between the channels are dried and dead trees resulting from the fires. **C:** Part of a 66-km long primary channel connecting the parent primary channel in the north to the Kapuas river in the south. Courtesy by CRISP Singapore.

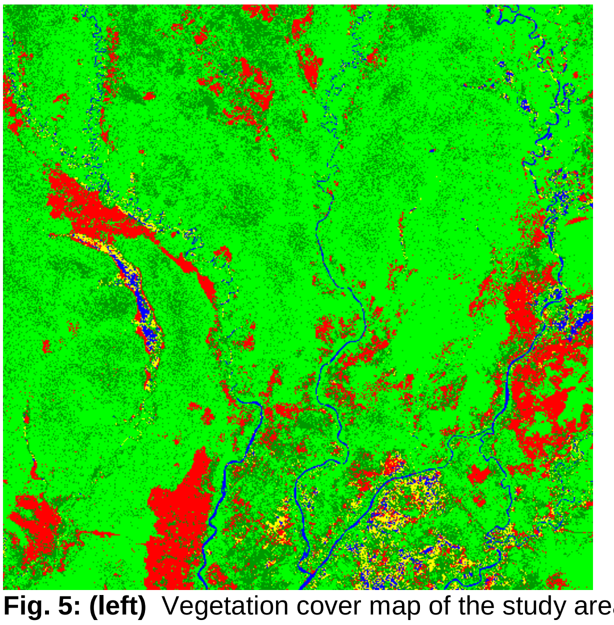
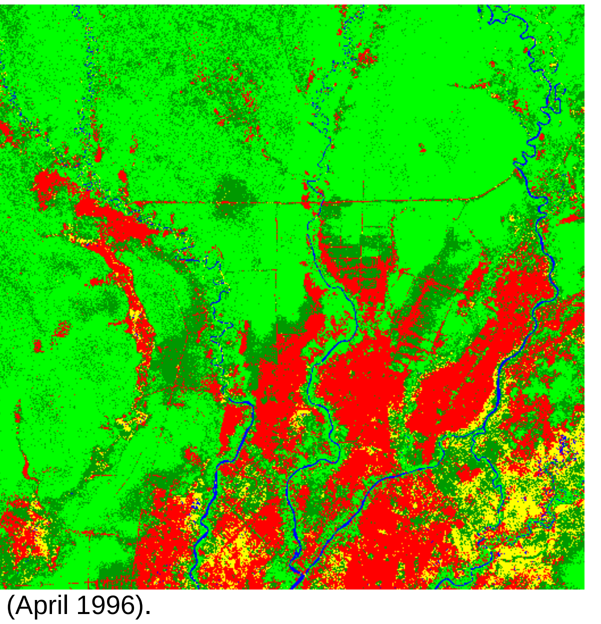



Fig. 5: (left) Vegetation cover map of the study area (April 1996).
Fig. 6: (right) Vegetation cover map of the study area (Oct. 1997)
Legends for both maps: Red: Clearings and settlements. **Green:** Dense forest. **Dark green:** Burnt/degraded peat swamp forest with low biomass. **Yellow:** Grass or sparse vegetation. **Blue:** open water (catchments and rivers). Courtesy by CRISP Singapore.

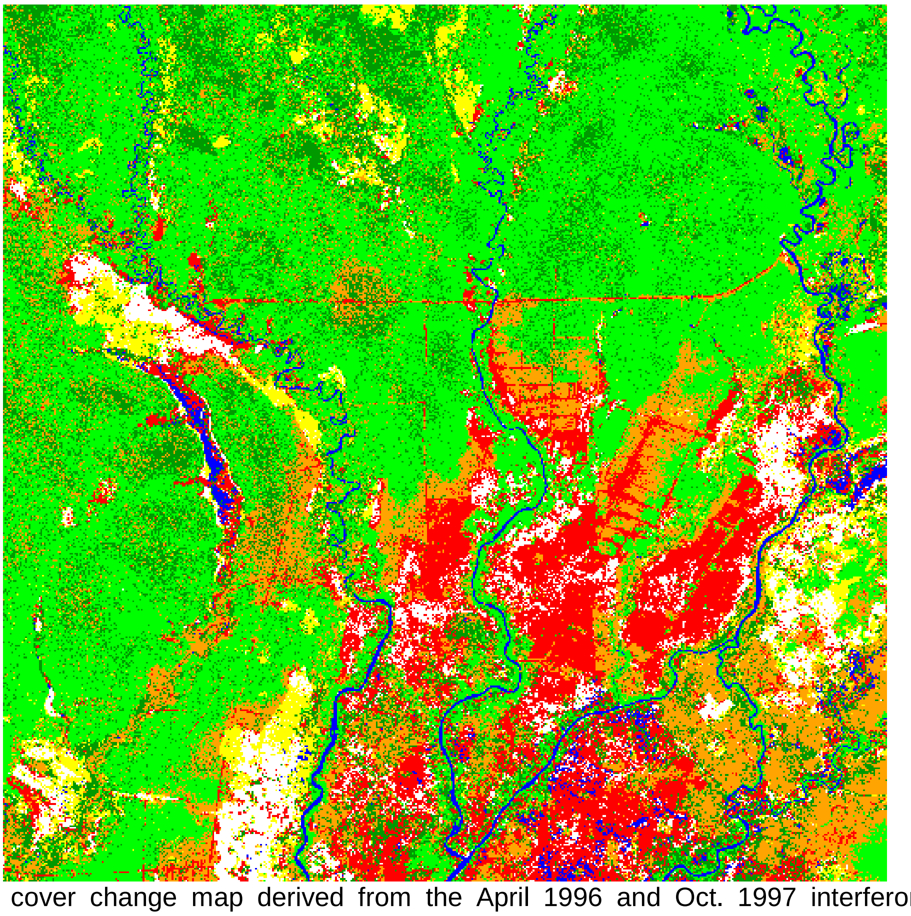


Fig. 7: Land cover change map derived from the April 1996 and Oct. 1997 interferometric SAR datasets. The areas affected by the 1997 fire are coloured in red and orange. They occupy about 25% of the total area surveyed in the ERS images. **Red:** New clearings, fire burnt scars. **Orange:** Degraded forests, standing dead trees. White: Settlements, old clearings. **Yellow:** Old clearings with vegetation regrowth. **Green:** Remaining dense forests. **Dark green:** Remaining low biomass forests, shrubs. **Blue:** Rivers, catchments, water bodies. The channels are not resolved in the image. They are visible due to clearing of vegetation on both sides of the channels. Courtesy by CRISP Singapore.

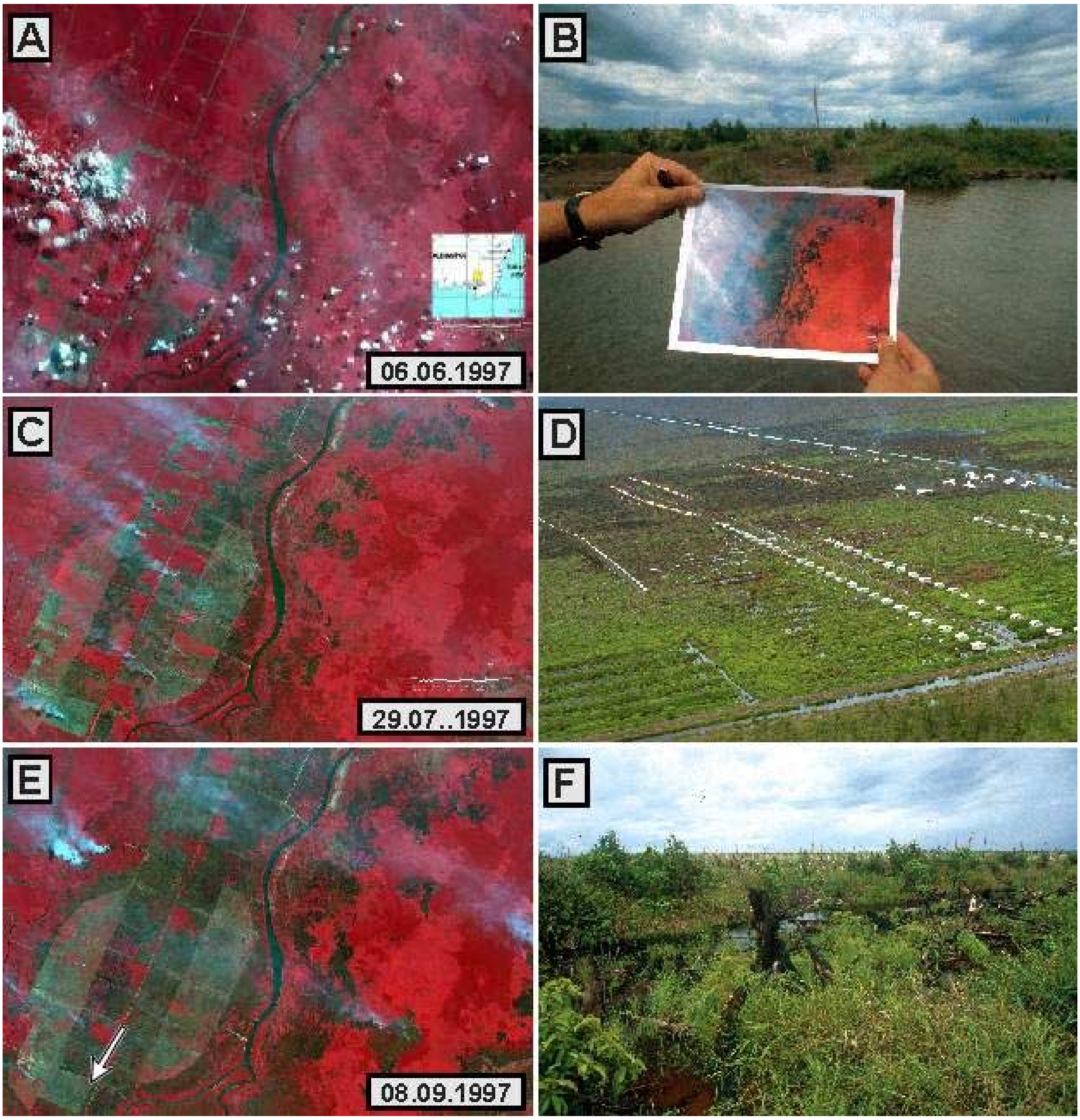


Fig. 8: SPOT quick look images of the study area acquired on 6.June, 29.July and 8.September 1997. Several smoke plumes due to fire activities can be clearly seen. **A:** Spot image from 6. June 1997 before the fires with Barito river. **B.** Ground photo in the Dadahup area. **C:** Land cleared by fires in 29. July 1997**.** **D:** Aerial photo of transmigration houses **E:** Spot image from 8.9.1997, dark green areas in Fig. 4. **F:** Ground photo with cleared forest.

Fig. 9: LANDSAT-TM images (RGB = Bands 543) of the Mega Rice Project area in Central Kalimantan near Dadahup acquired on 10 May 1996 before the 1997 fire (top left panel **A**) and on 29 March 1998 after the fire (Bottom panel **C**). Each image covers an area 44km by 58km. Peat swamp forests appear in shades of green, clear-cuts in shades of pink and purple. Burnt areas appear in red in panel **C**. The letters and arrows in panel **C** indicate the locations of the aerial and ground photos shown in Figure 10. For comparison, ERS interferometric SAR images of April 1996 (before fire, top right panel **B**) and Oct. 1997 (during fire, bottom right panel **D**) extracted from Fig. 3 and Fig. 4 are also shown.

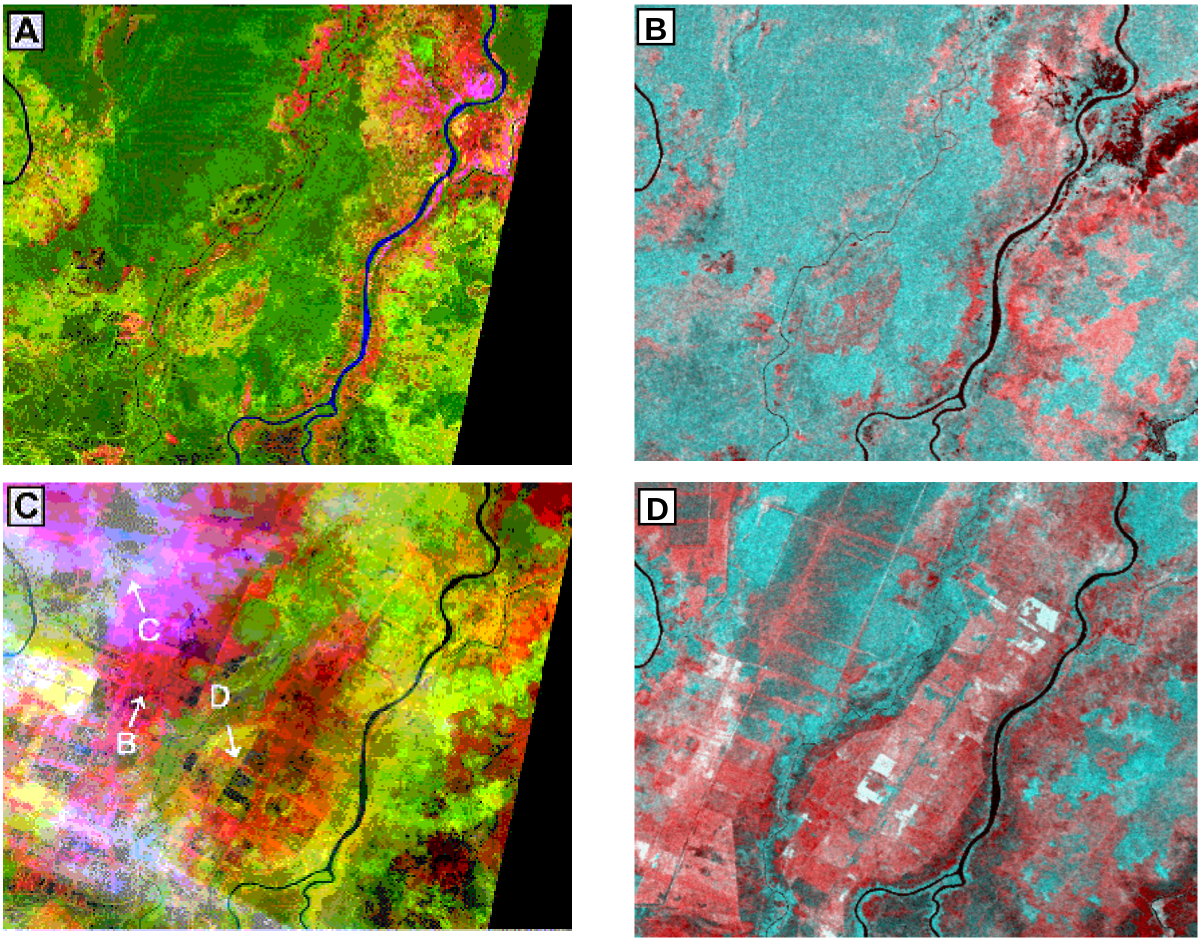


Fig. 10: Aerial photos acquired during a flight on 13 June 1998. **A:** PPC and burnt scars at Kapuas river with sluices, **B:** PPC interrupted by black water river Mentangai crossing the channels.

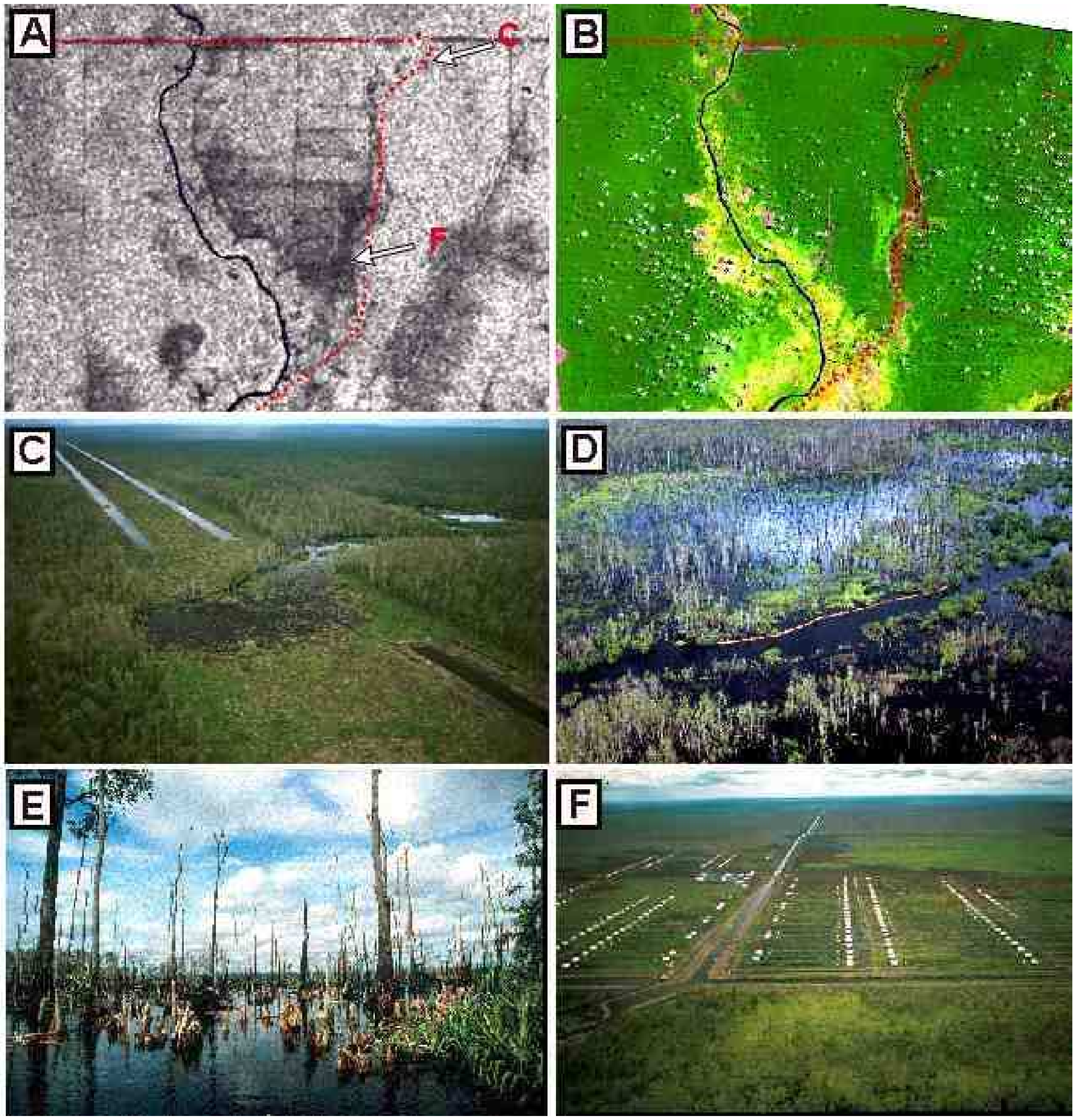


Fig. 11: A: ERS-image (18 Sept. 1997) showing the rivers Kapuas and black water river Mentangai, the new channels and the flight route from 3 Nov. 1998 (dotted red lines). **B:** LANDSAT-TM image (10 May. 1996, RGB = 543) of the same area without small channels. **C:** Mentangai river crossing the main channel, channel construction had to be interrupted. **D:** Illegal logging along Mentangai river. **E:** Dead trees along Mentangai river, remnants from the great fire in 1997. **F:** New Transmigration settlement established after the land clearing by fire in 1997 (compare LANDSAT image in Fig. 2 and !!B) not yet inhabited, location indicated by arrow in A.

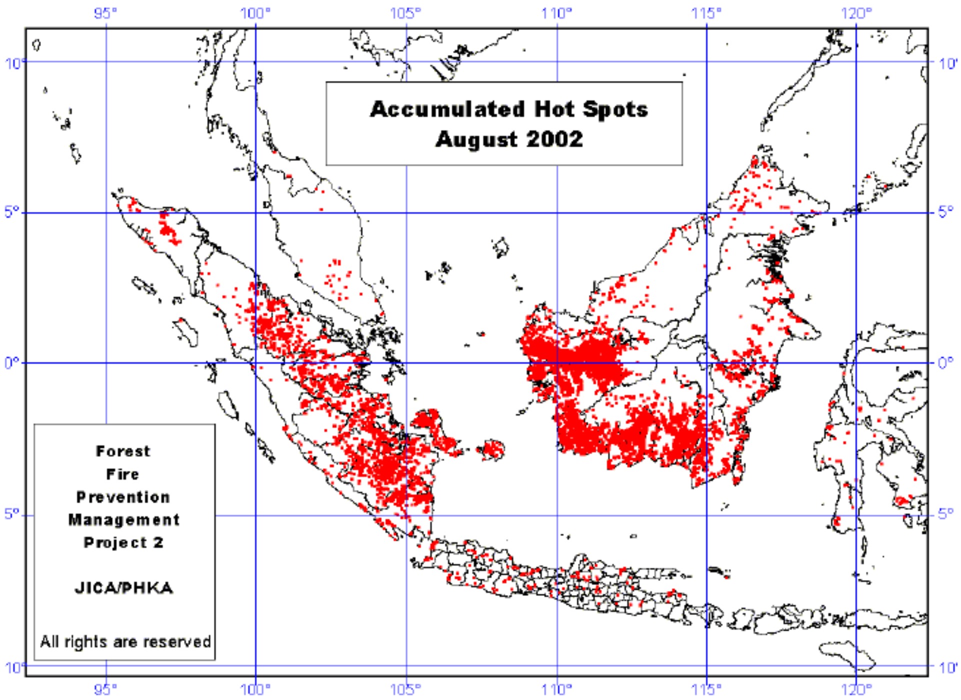


Fig.12: Accumulated NOAA Hot Spots in **Aug. 2002 for Borneo, Sumatra, Java and Sulawesi.**. Courtesy by JICA.

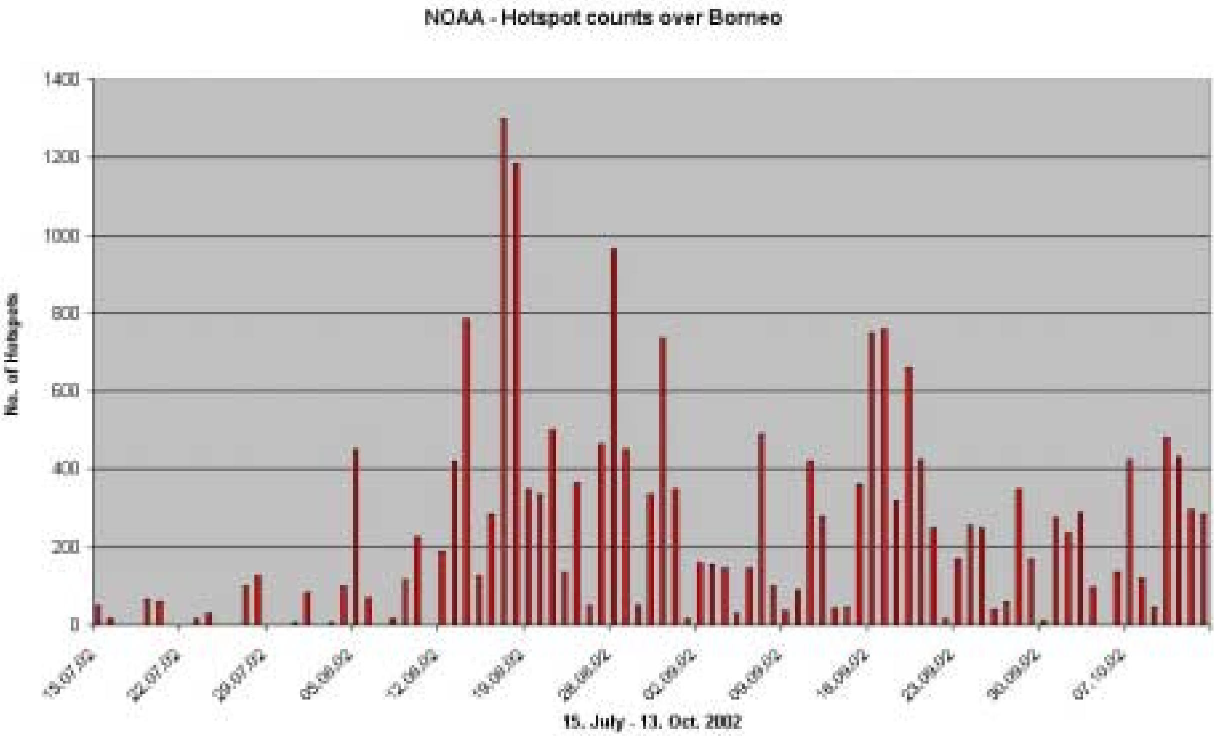


Fig. 13: NOAA- Hot spots detected in Borneo over a period of three month. It started with the fires End of July 2002 and showed around the 17.August 2002 the most hot spot counts with 1300 and one month later around the 17. Sept. 2002 again high values with 760 hot spot counts. The fires, smoke and haze continued up to the end of Oct. 2002. Courtesy by National Environmental Agency, Singapore.

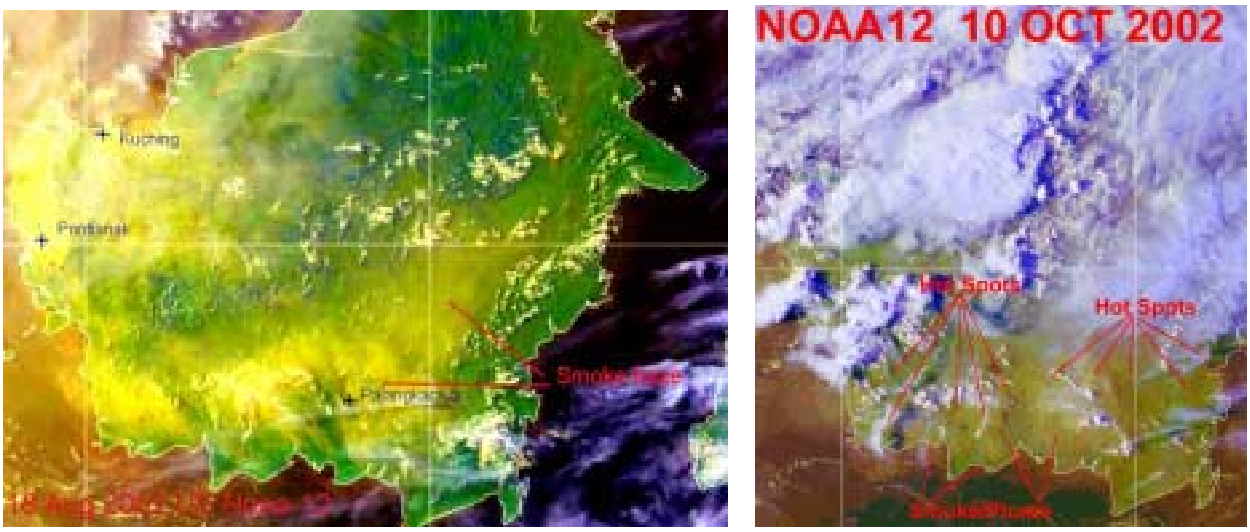


Fig. 14: Island Borneo with a clear NOAA12 image from the 18. August 2002 showing smoke and haze (left). On the 10. Oct. 2002 many clouds are visible covering the north part of Borneo (right). In the southern area many hot spots, smoke, plumes and haze were monitored (right). Courtesy by National Environmental Agency, Singapore.

Fig. 15: Modis image acquired on 18. August 2002 showing many fires, smoke and plumes over Central Kalimantan, compare hot spot counts in Fig. 13. Palangkaraya is totally covered by fires and smoke. Courtesy by NASA.

Fig. 16: Fires in deep peatland south of Palangkaraya, Central Kalimantan from Sept. 2002, photos courtesy by Prof. J. Rieley, University of Nottingham and Dr. Takahashi, University of Hokkaido.

Fig.17: Landsat image (118-62, RGB=543) acquired on 20. Aug. 2001 from the MRP area located between Kapuas (left) and Barito rivers (right) with Lamunti and Dadahup villages. The time of acquiring the image is again during dry season visible with smoke plumes four years after the ENSO of 1997 and one year before ENSO 2002. The MRP channel system can be seen and it is mostly not working. The clear cuts of the peatland is shown in light green colour with regrowth of bush land. Red colours around the channels are burnt cars and fresh clear cuts, compare Fig. 2, 9A,C+F, and 11. The remaining PSF (dark green colour) in the upper part of the image is strongly reduced see Figure 2.